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64-multidetector CT anatomical assessment of the feline bronchial and pulmonary vascular structures

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Abstract: OBJECTIVES: The aim of the study was to provide a detailed anatomical study of the feline bronchial and vascular structures by using CT angiography (CTA). METHODS: Adult cats with no respiratory clinical signs were enrolled in a CTA protocol to provide an anatomical study of the thorax. The dimensions, number of branches and branching pattern (monopodial vs dichotomic) of both bronchial and pulmonary vascular structures were evaluated under positive inspiration apnoea. A linear generalised estimating equations analysis (Spearman's rho) was used to identify statistical correlation between tracheal diameter, age and body weight of the cats. RESULTS: Fourteen cats met the inclusion criteria. The pulmonary arteries had larger diameters than the pulmonary veins, and the pulmonary veins had larger diameters than the bronchial structures. A higher number of segmental bronchial and pulmonary vascular branches was observed in the left caudal lung lobe than in the other lobes. The monopodial branching pattern of both bronchial and pulmonary vascular structures was predominant in all cats of our study (100%) in cranial, caudal and right middle lung lobes, while a dichotomic branching pattern of the bronchial and pulmonary vascular structures of the accessory lung lobe was seen in 13 cats (93%). Thirteen cats (93%) had three pulmonary vein ostia, and one cat (7%) also presented with an additional left intermediate pulmonary vein ostium. Variation in the number of segmental pulmonary vein branches was noted in the right caudal lung lobe. There was no statistical correlation between tracheal diameter, age and weight. CONCLUSIONS AND RELEVANCE: Architecture of the feline bronchovascularr structures belongs to a mixed type of monopodial and dichotomic branching pattern. In cats, the pulmonary venous drainage system predominately presents three pulmonary vein ostia. Variations in the type of formation and the number of branches of the pulmonary venous drainage system were noted.

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64-MULTIDETECTOR COMPUTED TOMOGRAPHY ANATOMICAL ASSESSMENT OF THE FELINE BRONCHIAL AND PULMONARY VASCULAR STRUCTURES

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Key words: computed tomography, angiography, feline, thorax, pulmonary vessels

Running head: feline computed tomography pulmonary angiography

Abstract

Objectives The aims of the study were to document a detailed anatomical study of the feline bronchial and vascular structures by using computed tomography angiography (CTA).

Methods Adult cats with no respiratory clinical signs enrolled in a CTA protocol to provide an anatomical study of the thorax. The dimensions, number and the branching pattern (monopodial vs dichotomic) of the bronchial and vascular structures were evaluated. A linear generalized estimating equations analysis (Spearman r) was used to identify statistical correlation between tracheal diameter, age and weight of the cats.

Results Fourteen cats met the inclusion criteria. The pulmonary arteries had major dimensions than pulmonary veins and the pulmonary veins had major dimensions than the bronchial structures. An increased number of segmental broncho-vascular branches was observed in the left caudal lung lobe compared to the remaining lobes. The monopodial branching pattern was predominant in all cats of our study (100 %) in the cranial lung lobes, caudal and right middle lung lobes, while a dichotomic branching pattern of the accessory lung lobe was seen in thirteen cats (93 %). Thirteen cats (93%) had three pulmonary vein ostia while one cat (7%) presented moreover a left intermediate pulmonary vein ostium. Variation of number of the segmental pulmonary vein branches was noticed in the right caudal lung lobe. There was no statistical correlation between tracheal diameter, age and weight.

Conclusions and relevance Architecture of the feline bronco-vascular structures belongs to a mixed type of monopodial and dichotomic branching pattern. In cats the pulmonary venous drainage system forms predominately three pulmonary vein ostia. Variations of the type of formation and the number of the pulmonary venous drainage system were noted.

Introduction

Multidetector Computed Tomography (MDCT) has become a routine examination in small animal's veterinary medicine and demonstrated the utility and accuracy as an advanced imaging diagnostic tool for screening of feline thoracic pathologies. [1-10] A CT comparison of the normal cross-sectional anatomy of the feline thorax has previously been described.[11] More recently, several reports described threshold values for pulmonary artery and bronchial lumen diameters in cats with and without cardio-pulmonary pathologies in order to define imaging criteria useful to diagnose feline bronchiectasis.[12-14] Bronchial wall thickness was also evaluated in healthy and asthmatic cats to correlate this parameter with feline asthma.[15] Nevertheless, to the best of our knowledge, literature lacks information about detailed imaging and gross anatomy description of the feline bronchial tree, pulmonary arteries, pulmonary veins and pulmonary venous ostia.

The aim of this study was to provide an anatomical description of the bronchial tree, the pulmonary arteries and pulmonary veins by using 64-MDCT angiography.

Materials and methods

This is a prospective descriptive anatomic study. The study was approved by the specific ethical and welfare committee prior to publication. Twenty cats with no history of respiratory disease, normal clinical examination, normal complete blood test and urine analysis, negative fecal examination and normal thoracic CT were included. Exclusion criteria included CT findings compatible with thoracic and pulmonary disease. The study was performed with a 64-MDCT scanner Toshiba Aquilion 64. After pre-anaesthetic assessment, each cat received 25µg/Kg of dexmedetomidine and 0.1 mg/Kg of butorphanol, injected intramuscularly. The cats were induced to general anaesthesia with 1-2 mg/Kg of propofol injected intravenously to effect and intubated via an endotracheal. General anaesthesia was maintained with isoflurane in 100% oxygen through a bain breathing system, with an oxygen flow-rate of 2 L/min. Normocapnia was maintained with intermittent positive pressure ventilation whenever necessary.

Cats were positioned in sternal recumbency with the limbs extended forward. Pre- and post-contrast series of the thorax were performed during inspiratory apnea (peak inspiration pressure maintained at 15 cm H_2O) by using 0.5 mm slice thickness, 0.5 second tube rotation time, 120 kVp and 50 mA, scanning from the thoracic inlet till the cranial abdomen. A saline intravenous flush of 3 ml/Kg with a rate of injection 2 ml/sec was performed twice, once before the injection of contrast medium and once immediately afterwards. Iodinated non-ionic contrast medium (Iobitridol, 300mgI/ml) was injected via a dual-barrel injector system with heating cuff, extravasation detection device and communication interface between the scanner and the injector. Contrast medium was kept at 37° within the dual/barrel injector system and injected with a constant rate of 2 ml/sec, with a total dose of 600 mgI/ kg and maximum pressure of 300 lb/in^2.

To determine the starting delay of the post-contrast series, the time-to-peak enhancement was set by using a bolus tracking technique. The region of interest was drawn within the descending aorta at the level of the eighth thoracic vertebra, arbitrary choosing a descending aorta opacification threshold of 115 Hounsfield Units (HU) above baseline (Sure Start proprietary software, Toshiba

Medical Systems) for starting the post contrast thoracic scan. Images were reconstructed with soft tissue and lung algorithms and the acquired data were exported to a dedicated workstation (Vitrea, Vital images) for post-processing elaboration of the data. Multiplanar reformatted reconstruction surface rendering, maximum intensity projection, volume rendering and endoluminal segmentation were used to evaluate the pulmonary vasculature and bronchial anatomical structures. Each segment of the bronchial tree was named accordingly to the endoscopic classification system as previously described (Table 1).[16]

All the images were reviewed by two investigators (IP and MC) and the following parameter were assessed:

a) number and diameter of the tracheo-bronchial segments and pulmonary arteries and veins.

The diameter of the tracheo-bronchial tree and vascular segments was calculated by applying calipers from inner to inner edge, with a constant window level of -340 and window width of 1700. Each segment was measured four times in three planes (i.e. two times in transverse, one in sagittal and one in coronal planes). The tracheal diameter was measured immediately proximal to the bifurcation and each lobar and segmental bronchial or vascular branch was measured just distal to its origin.

b) monopodial or dichotomic pattern of distribution of the bronchial and vascular structures. In the monopodial distribution, the main central bronchial or vascular segment branches off in multiple smaller segments, while in the dichotomic distribution the main central segment bifurcates in two branches of equal diameters and from each of those multiple smaller branches rise (Figure 1).

c) number of the pulmonary vein ostia within the left atrium and classification of the pulmonary venous drainage system just before the opening in the pulmonary vein ostia (separate, short common trunk and long common trunk) as seen in (Figure 2).

The pulmonary venous drainage system was classified as:

- separate, when the pulmonary veins drained independently in the left atrium
- short common trunk, when two or more pulmonary veins fused by forming a “short neck” just before opening into the left atrium
- long common trunk, when two or more pulmonary veins fused by forming a “long neck” just before opening into the left atrium

Statistical analysis

A Spearman r analysis was used to identify statistical correlation between tracheal diameter and age or body weight of our group of cats. Analyses were achieved with commercial software (IBM SPSS Statistics, release 22.0.0.0, 64-bit edition, IBM Corporation and others 1989, 2013). Values of $P < 0.05$ were considered statistically significant.

Results

Six cats were excluded from the study due to detection of pulmonary lesions (5 cats) and mild spontaneous pneumothorax (1 cat). Fourteen domestic short hair cats, nine males and five females, met the inclusion criteria with a median age of 1.7 years old (range from 1 to 6 years old) and median body weight of 4.3 kg (range from 2.7 – 6.7 kg).

Number and diameter of broncho-vascular segments

The tracheo-bronchial tree ramification was consistent in all fourteen cats. The trachea bifurcated into the right and left main bronchi. The right main bronchus branched off in the right cranial, middle, accessory and caudal bronchi and the left main bronchus further divided in the left cranial and caudal bronchi.

The right cranial bronchus (RB1) ran cranio-ventrally bifurcating in two main dorso-lateral and ventral branches and further in multiple segmental smaller bronchi. Two main pulmonary arteries and veins ran close to the respective bronchial structures, one for the ventral (main branch) and one for the dorsal-lateral segments. The two main pulmonary veins of the right cranial lobe converged before receiving the drainage of the pulmonary vein of the middle lung lobe.

The right middle bronchus (RB2) originated directly from the right main bronchus just caudal to the origin of the RB1, ran caudo-ventral close to the cardiac surface and further divided in multiple cranio-ventral and caudo-ventral branches. The pulmonary arteries and veins of the right middle lobe ran adjacent to the corresponding bronchial branches.

The accessory bronchus (RB3) originated from the medial wall of the right caudal bronchus at level of his origin, ran ventro-medially and bifurcated in a ventro-medial and caudal branch such as its corresponding pulmonary arterial and venous branches. The pulmonary veins of the accessory lobe converged before joining the right caudal pulmonary vein.

The right caudal bronchus (RB4) branched off as direct continuation of the right main bronchus, just caudal to the origin of the RB3. The RB4 had three main segmental bronchial branches (ventral, caudo-ventral and caudal) followed by corresponding pulmonary arteries and veins (Figure 3a). In eight (57%) cats (6 males, 2 females), we noticed the absence of the caudo-ventral pulmonary vein; this district was drained by the adjacent ventral branch of the pulmonary vein of the right caudal lobe (Figure 3b).

The left main bronchus right after the tracheal bifurcation branched off immediately laterally the left cranial (LB1) and caudally the left caudal (LB2) lobar bronchi.

The LB1 further splitted in two rami, one running cranio-ventrally and one caudo-ventrally, giving origin to multiple segmental dorsal and ventral branches.

The LB2 originated as direct continuation of the left main bronchus, just caudal to the origin of the LB1. The LB2 branched in three main rami (ventral, caudo-ventral and caudal). The pulmonary arteries and veins of LB2 branched off accordingly to the bronchial ramifications.

The mean diameters of the bronchial and vascular structures were summarized (Table 2).

The pulmonary arteries had a greater diameter than the corresponding pulmonary veins and the pulmonary veins had a greater diameter to the corresponding bronchial segments. An increased number of segmental broncho-vascular branches was observed in the left caudal lung lobe as compared to the remaining lung lobes (Table 3).

Monopodial or dichotomic pattern of distribution of the bronchial and vascular structures

The type of distribution pattern of the bronchial tree was summarized (Table 4). In our case series, most of the broncho-vascular segments matched a monopodial classification.

More specifically, in all fourteen cats of our study, both cranial and caudal and the middle lung lobes had a monopodial branching pattern. In thirteen cats the accessory lobe had a dichotomic branching pattern while just one cat had a monopodial branching pattern.

Number of the pulmonary vein ostia within the left atrium and classification of the pulmonary venous drainage system

The pulmonary veins drained into the left atrium via three ostia (right cranial, left cranial and caudo-dorsal) in all cats of our study (Figure 4).

The right cranial ostium (RCO) received the drainage of the right cranial and middle lung lobes. The right cranial lobar pulmonary vein converged with the right middle lobar pulmonary vein by forming a long common trunk before opening into the right cranial part of the left atrium (i.e the right cranial ostium) in all cats (100%) of our study.

The left cranial ostium (LCO) hosted the drainage of the lobar pulmonary veins of the cranial and caudal portion of the left cranial lung lobe which joined together via a long common trunk before opening into the left cranial part of the left atrium (i.e. left cranial ostium). The long common trunk type of venous drainage between the left cranial lobar veins was noted in thirteen cats (93%), while in one cat (7%) the lobar pulmonary veins of the cranial and caudal portion of the left cranial lung lobe opened up separately and respectively into the left atrium via the LCO and an intermediate adjacent ostium (Figure 5).

The caudo-dorsal ostium (CDO) received the drainage of both caudal and the accessory lobar pulmonary veins. In all cats (100%), the right caudal lobar pulmonary vein received the accessory lobar pulmonary vein and fused with the left caudal lobar pulmonary vein by forming a short common venous trunk which opened into the caudo-dorsal part of the left atrium (i.e. the caudo-dorsal ostium).

There was no statistical correlation between the tracheal diameter, age and body weight of our group of cats.

Discussion

We successfully depicted the feline broncho-vascular structures by using a 64-MDCT in fourteen cats. In all cats of our study the trachea bifurcated in a right and left main bronchi, consistent with the up to date literature and similar to the canine's anatomy.[16-20] No statistical correlation was observed between tracheal diameter, age and body weight; we deemed this logical due to the fact that our population included adult cats (over 1 year old) in which a complete physical growth and maturation is expected.

Accordingly, to the previous feline literature, we noticed that the pulmonary arteries have a greater diameter than the corresponding bronchi.[12,13,15] On the other hand in normal dogs the bronchi tend to have a larger diameter than the adjacent pulmonary arteries with a bronchial lumen to pulmonary artery ratio range between 0.8-2.0.[21,22]

To the best of our knowledge, no imaging studies have previously correlated the diameter of the feline pulmonary arteries with the corresponding pulmonary veins. In all cats of our study we consistently noticed that the pulmonary veins had a smaller diameter as compared to the corresponding arteries; this finding is in agreement with medical literature.[23,24] The pulmonary vein to pulmonary artery ratio has been recently proposed in dogs as echocardiographic index to identify early condition of left sided congestive heart failure.[25,26] Further studies correlating the diameter of pulmonary veins and arteries in cats affected by left sided cardiomyopathy are needed to understand if such an index could be a useful diagnostic tool also in the feline population.

Accordingly, to the literature the monopodial lobar broncho-vascular branching pattern is predominant in dogs while the human bronchial tree is consistent with a dichotomic classification.[27-29] No monopodial or dichotomic classification has been proposed for the feline population. Based on our results, the feline thorax demonstrated a predominant lobar monopodial architecture with exception of the accessory lobe, which demonstrated a prevalent dichotomic branching pattern. The dichotomic or monopodial bronchial branching pattern may influence the distribution of gas within the lungs and so that different dose of aerosol could be achieved among different species.[27,28] In dogs is believed that due to the monopodial branching pattern there is a preferential distribution of ventilation to peripheral regions of the lung, more pronounced during higher inspiratory flow rates.[28] Further studies are needed to investigate the possible correlation between the predominant feline monopodial bronchial branching pattern and the preferential peripheral lung ventilation.

Pulmonary variations of the venous system are well studied in humans since pulmonary veins are an important source of ectopic atrial electrical activity, frequently initiating paroxysms of atrial fibrillation.[30] In humans four pulmonary vein ostia are usually present with variable distribution and variations of the pulmonary vein drainage systems has been correlated with arrhythmia or in one case with high altitude pulmonary edema.[31-33] Right-sided venous drainage system is more variable than the left one.[34] Canine anatomical variations of the pulmonary and cardiac venous system are poorly reported.[35,36]

To our knowledge this is the first report that attempted to classify the pulmonary venous drainage and corresponding pulmonary vein ostia in cats. The long common trunk venous drainage was the predominant type of pulmonary vein anastomosis seen in our case series before emptying within the left and right cranial pulmonary vein ostia; a vascular variation was detected in just one cat in which an additional intermediate ostium was detected between the left cranial and the caudo-dorsal ostia. The short common trunk venous drainage was the only type of pulmonary vein anastomosis of the caudo-dorsal pulmonary vein ostium.

Feline cardiogenic pulmonary edema is well documented and showed extreme variability in its radiographic distribution as compared to the canine species; till now there is no clear explanation of the variable presentation of the feline cardiogenic pulmonary edema.[37,38,39]

Further studies are needed to identify possible correlation between pulmonary venous drainage variation in the left atrium and manifestation of feline cardiovascular imbalances.

The limited number of cats and the absence of gross anatomy were the two main limitations of our study. A third limitation was the absence a complete cardiac and echocardiographic examination, fact that we could not rule out an underlying non-structural cardiac disease.

In conclusion, thoracic CTA in cats showed that pulmonary arteries had greater dimensions than the pulmonary veins while the pulmonary veins had greater dimensions than bronchi. The feline broncho-vascular branching pattern is predominantly monopodial. There was no statistical correlation between the tracheal diameter, age and body weight of our group of cats. In all cats of our study the pulmonary veins fused by forming three pulmonary vein ostia and formed a long common trunk in the left and right cranial pulmonary vein ostia and a short common trunk in the caudo-dorsal pulmonary vein ostium

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